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Laser treatment of electro-spark coatings deposited in the carbon steel substrate with using nanostructured WC-Cu electrodes

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Abstract

The aim of this work was to investigate the influence of laser treatment for the improving mechanical and tribological properties coatings fabricated in the C45 carbon steel by ESD process. The studies were conducted using WC-Cu electrodes produced by sintering nanostructural powders and molten with a laser beam. The tests proved that ESD WC-Cu coatings are characterized by lower hardness and friction coefficient, but higher roughness. The result of laser processing improves structure by refinement, healing of microcracks and pores of ESD coatings. Laser treated ESD coatings can be applied in sliding friction pairs and as protective coatings.

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Keywords: Electro-Spark Deposition (ESD); laser treatment; coating; roughness; microstructure; microhardness; tribology

1. Introduction

There are many methods for producing surface coatings, for example electroplating or plasma spraying. Very thin deposited layers can be manufactured by vapor deposition method. Various surface treatment techniques have been developed to improve the desired properties of the deposited layers, produced in the substrate material. Some of these methods are expensive and should be used only for

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unique applications, where the high cost is justified. However, for most applications, there is a need for generation low cost coatings of good properties. The aim of this work is to improve a widely used low cost method of electro-spark deposition (ESD). It has been already recognized as an economically effective surface coating [1-6]. ESD is also widely used for its relative low cost equipment required to run this process. The deposition of the coating is achieved by an electrical circuit, which generates sparks between the electrode and the workpiece. Electrical pulses of high frequency and high direct current between the electrode (anode) and work-piece (cathode) release very hot micro-particles of electrode material, resulting in continuous micro-welding coating on the work-piece surface. Important advantage is that the coating is bonded to the substrate with relatively low heat input. The energy savings effect is based on micro-particles heated region, while the body of the work-piece remains at low temperature. ESD has been known by several other terms such as Spark Hardening (SH), Electric Spark Toughening (EST), and Electro-Spark Alloying (ESA).

Electro-Spark Deposited (ESD) coatings have some disadvantages, which can be easily eliminated. For example one of the proposed methods can be laser treatment; where laser beam is used for surface polishing, surface geometry formation, surface healing or for homogenizing the chemical composition of the coatings deposited [7-9].

The work discusses the properties of electro-spark deposited WC-Cu coatings under applied laser treatment. The properties were established based on the results of a microstructure analysis, surface roughness, microhardness and tribological studies.

2. Experimental

In the experiment, the coatings were electro-spark deposited with using a WC-Cu (50% WC and 50% Cu) electrode with a cross-section of 4 x 6 mm (the anode) - onto samples made of carbon steel C45 (the cathode).

The powders were mixed for 30 minutes in the chaotic motion *Turbula T2C* mixer. The mixture was then poured into rectangular cavities of a graphite mould, each 6 × 40 mm in cross-section, and consolidated by passing an electric current through the mould under uniaxial compressive load. A three minute hold at 950 °C and under a pressure of 40 MPa permitted obtaining electrodes of porosity < 10 % and strength sufficient to maintain integrity when installed in the electrode holder.

The equipment used for electro-spark deposited was an EIL-8A model. Based on the previous our work and instructions given by the equipment manufacturer, the following parameters were assumed to be optimal for ESD, for example: voltage $U = 230$ V, capacitor volume $C = 150$ μ F and current intensity $I = 0.7$ A. In Fig. 1 the electro-spark deposition equipment is illustrated.



Fig. 1. View of EIL-8A electro-spark deposition – equipment

Then, the coatings were treated via Nd:YAG laser (impulse mode), model BLS 720. The samples with electro-spark deposited coatings were modified by laser with using following parameters: laser spot size diameter $d = 0.7$ mm, laser power $P = 60$ W, scan speed $v = 250$ mm/min, nozzle-workpiece distance from the substrate $\Delta f = 6$ mm, pulse duration $t_i = 0.4$ ms, pulse repetition frequency $f = 50$ Hz, beam shift jump $S = 0.4$ mm and nitrogen gas shield $Q = 25$ l/min.

3. Results and Discussion

3.1. Microgeometry measurements

The roughness of the WC-Cu coatings was analyzed by using the Taylor-Hobson Talysurf CCI surface optical profiler. Roughness profiles are routinely measured by dragging a stylus along the laser beam track whereas the maximum values of the arithmetic average departure from the surface plain are reported to occur in the perpendicular direction. Therefore in this study an average value of R_a was calculated for each coating from readings taken on evenly divided sampling lengths running parallel to the electrode/laser beam motion and on similar lengths at 90° . It was found that the employed surface treatments increased the average roughness value (R_a) from $0.41 \div 0.44$ μm for the C45 steel substrate up to $2.37 \div 3.67$ μm and $3.05 \div 4.26$ μm for the WC-Cu coatings in as-deposited and laser treated condition, respectively.

In Figures 2 and 3 an examples of the two-dimensional surface microgeometry measurement of the WC-Cu coatings before and after laser treatment are depicted.

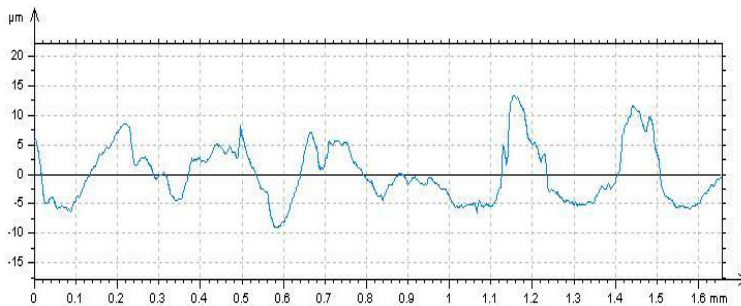


Fig. 2. Surface microgeometry of the WC-Cu coating deposited

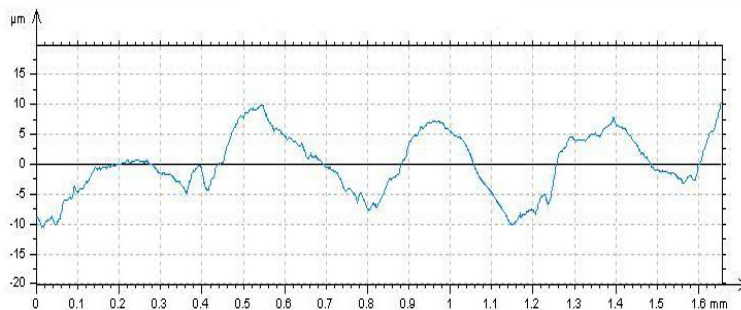


Fig. 3. Surface microgeometry of the WC-Cu coating deposited after laser treatment

From the measurement results it is clear that there is an increase in the roughness of the WC-Cu coatings after laser treatment. The higher roughness resulted from the tensile forces acting on the surface, and accordingly, the motion of the liquid metal. A non-uniform distribution of temperature in a laser beam (mod TEM₀₀) caused the non-uniformity of the surface profile after solidification, which, to some extent, reflects the distribution of energy in the melted zone. If pulse laser treatment is applied, it is assumed that the main factor affecting the surface profile after solidification is the pressure of vapor causing the disposal of the material from the central zone and the production of characteristic flashes on the boundary between the melted and unmelted zones.

3.2. Microhardness tests

The microhardness was determined by using the Vickers method (Microtech MX3 tester). The measurements were performed under a load of 0.4 N. The indentations were made in perpendicular microsections in three zones: the white homogeneous difficult-to-etch coating, the Heat Affected Zone (HAZ) and the substrate. The test results for the electro-spark deposited Cu-Mo coating before and after laser treatment are shown in Tables 1 and 2. Electro-spark deposition shows changes in the microhardness of the material. The microhardness of the substrate after electro-spark deposition was on average 278 HV 0.4; the same value was reported for the substrate before the process. There was a considerable increase in microhardness after depositing the WC-Cu coating. The microhardness of the WC-Cu coating was approx. 643 HV 0.4, which gives increase of 131 %. The microhardness of the WC-Cu coating in the Heat Affected Zone (HAZ) after electro-spark treatment was 57 % higher than that of the substrate material. Laser treatment had a favorable effect on the changes in the microhardness of the electro-spark deposited of the WC-Cu coating. There was a decrease of 9 % in the microhardness of the WC-Cu coating.

Table 1. Results of the microhardness tests for the WC-Cu coating before laser treatment

Measured zones	Microhardness HV 0,04			Mean value HV 0,04
	Measurement number			
	1	2	3	
Coating	652	691	585	643
HAZ	428	464	421	438
Substrate	262	297	275	278

Table 2. Results of the microhardness tests for the WC-Cu coating after laser treatment

Measured zones	Microhardness HV 0,04			Mean value HV 0,04
	Measurement number			
	1	2	3	
Coating	594	621	635	617
HAZ	391	397	432	407
Substrate	276	288	273	279

3.3. Tribological tests

The T-01M pin-on-disc tribometer was employed to determine the dry friction behaviour of the WC-Cu coatings. A ball-on-flat contact geometry was chosen to measure the friction coefficient between a 100Cr6 grade steel ball, 6.3 mm in diameter, and the tested coating.

The testing was performed at the following parameters: load $Q = 14.7$ N, rotational speed $n = 427$ rpm, test duration $t = 3600$ s.

As it can be seen from Fig. 4, the 100Cr6 steel shows markedly higher friction coefficient on as-deposited coating than on its laser treated counterpart. Initially, the friction coefficient increases and after time of 3000 and 3200 s stabilizes at a level between $0.80 \div 0.82$ and $0.61 \div 0.64$ for the as-deposited and laser treated WC-Cu coating, respectively.

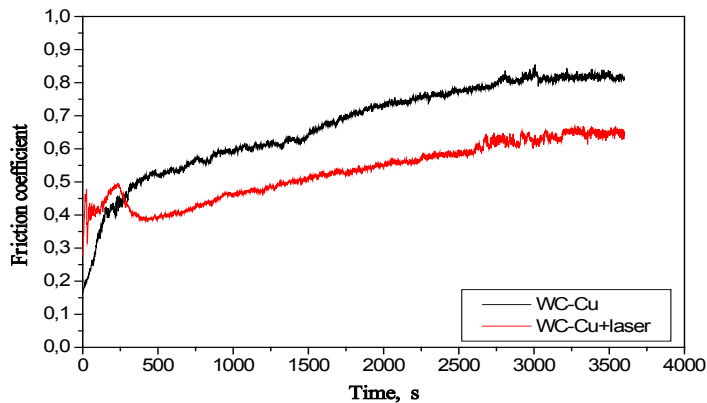


Fig. 4. Variation of friction coefficient over time between the steel ball and: as-deposited coating (black line); laser treated coating (red line)

3.4. Analysis of coating morphology

A microstructure analysis was conducted for WC-Cu coatings before and after laser treatment using a Scanning Electron Microscope (SEM), type Joel JSM-5400.

In Fig. 5 selected view of the surface microstructure of an electro-spark alloying WC-Cu coating is illustrated. It is clear that the thickness of the obtained layers was 36 to 60 μm , whereas the Heat Affected Zone (HAZ) reach depth of approximately 20 to 30 μm in the substrate (Fig. 5). A clear boundary between the coating and the substrate, pores and microcracks were observed. The electro-spark alloying WC-Cu coatings were modified by the laser treatment, which caused their composition changes. The laser treatment leads to the homogenizing of the coating chemical composition, structure refinement, and crystallization of phases supersaturated due to the occurrence of temperature gradients and high cooling rate.

The laser-modified outer layer does not indicate microcracks or pores (Fig. 6). There is no discontinuity of the coating-substrate boundary. The thickness of the laser treated WC-Cu coatings is from 40 to 74 μm . Moreover, the Heat Affected Zone (HAZ) is in the range of 30 to 45 μm , and the content of carbon in the zone is higher.

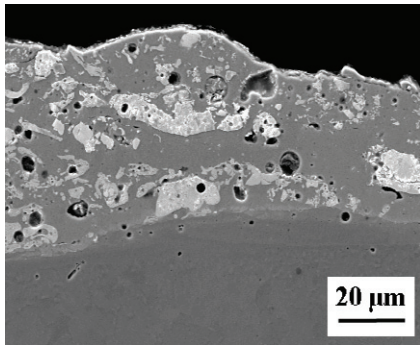


Fig. 5. WC-Cu coating microstructure after electro-spark alloying

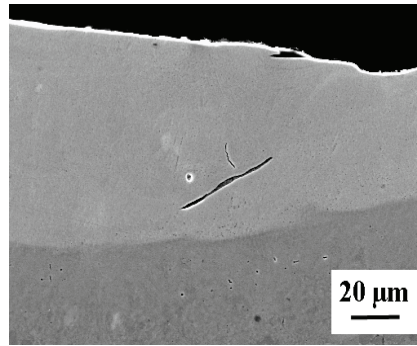


Fig. 6. Microstructure in the electro-spark alloying WC-Cu coating after treatment with an Nd:YAG laser

3.5. X-ray diffraction analysis

Using the X-ray diffraction method, the analysis of the phase composition of the examined coatings was performed with Philips PW 1830 instrument. Following parameters set up were applied: $K\alpha$ filtered radiation of a lamp with Cu anode, powered at 40 kV voltage and 30 mA current intensity. Tests were carried out for the angle 2θ in the range $30^\circ - 60^\circ$ and the scanning velocity of $0.05^\circ/3$ seconds.

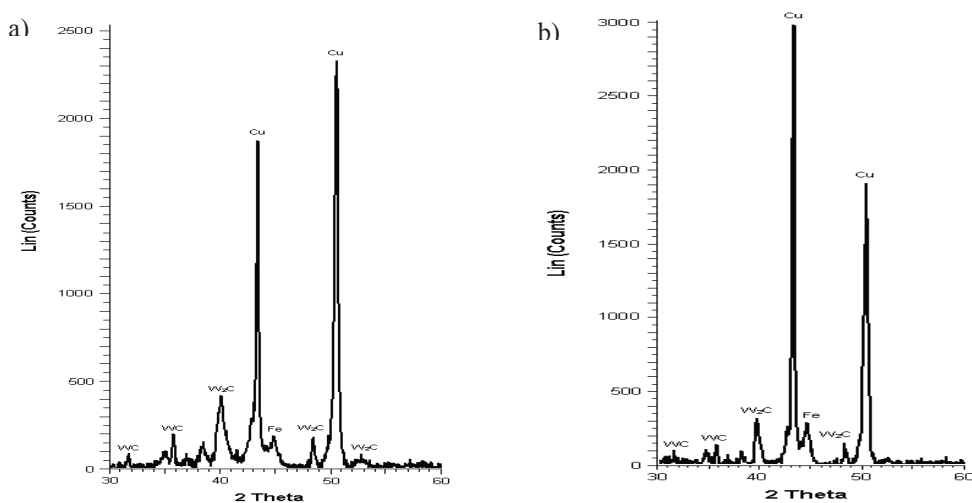


Fig. 7. X-ray diffraction pattern of the WC-Cu coating: (a) before laser treatment; (b) after laser treatment

The analysis of the phase composition of the WC-Cu coating (Fig. 7a) revealed that the surface layer of the coating consisted mainly of Cu and W_2C and a small admixture of WC and Fe. Laser treatment did not cause the melting of the WC-Cu coating to penetrate into the substrate material (Fig. 7b). The surface layer of the WC-Cu coating after laser treatment has the same composition as that of the coating before the treatment. The most intense peaks originate from Cu (Fig. 7a and 7b).

4. Conclusion

The following conclusions can be drawn from the analysis and test results:

- A concentrated laser beam can effectively modify the state of the surface layer, i.e. the functional properties of electro-spark coatings.
- Laser irradiation of coatings resulted in the healing of micro-cracks and pores.
- After laser treatment, the roughness of the electro-spark deposited coatings almost doubled. This phenomenon is unfavorable if we consider the quality and applicability of the coatings under certain service conditions. It is essential to determine which parameters of laser treatment cause the melting of the coating microroughness peaks (laser smoothing).
- Laser treatment caused a 9 % decrease in the microhardness of the electro-spark alloying WC-Cu coatings.
- The surface layer of the WC-Cu coating before and after laser treatment consists mainly of Cu and W₂C and a small admixture of WC and Fe.
- The average friction coefficient obtained for WC-Cu coating in tribological tests is approx. 22 % higher than the friction coefficient of the WC-Cu coating after laser modification (at the instant of their stabilisation).
- Coatings of that type can be applied to sliding friction pairs and can operate as protective coatings.
- Further research should involve measurements of internal stresses and investigations into the porosity of electro-spark coatings before and after laser treatment.

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